STORMWATER TREATMENT AREA NO. 3/4

ALTERNATIVES ANALYSIS

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3. TREATMENT SYSTEM PARAMETERS

3.1 INTRODUCTION

The Everglades Stormwater Treatment Areas (STAs) are the largest and most expensive treatment wetland project in the world. Their conceptualization, design, and construction are the outcome of an evolutionary sequence of observation, research, and practical application. Their primary purpose is to reduce the load and concentration of total phosphorus (TP) entering the Water Conservation Areas (WCAs).

The immediate predecessors to the Everglades STAs were the Lakeland Constructed Wetland Treatment System and the Iron Bridge Wetlands near Orlando, two large constructed wetlands in Florida designed for polishing municipal wastewaters. These two systems encompass nearly 500 ha each. Both became operational in 1987. Analysis of their early operational performance, as well as the results of research conducted by the South Florida Water Management District (District) in Boney Marsh, Chandler Slough, and in the WCAs (references 13-15), provided the technical basis for the Everglades Nutrient Removal Project (ENRP), a full-scale prototype for the STA concept.

The ENRP conceptual design was partially based on the analysis of data from the Iron Bridge Wetlands (references 16-18), and on the average TP retention rate of 1.67 g TP/m^2/yr in nutrient-enriched areas of WCA-2A (references 19, 20). Based on the availability of about 1,497 ha of state-owned land, it was presumed that the ENRP could remove 25 metric tons of phosphorus per year. The ENRP construction was concluded in September 1993 and has reported operational data since startup in August 1994. The ENRP will form a substantial proportion of STA-1W, which is now under construction and scheduled for completion in late 1999.

The current basis for design of the STAs was described in Part II, Section D of the Everglades Protection Project conceptual design report (reference 1). Estimation of required STA treatment areas was based on a preliminary model that relied on analysis of phosphorus deposition in WCA-2A (references 21, 22). Calibration of this model was solely based on data from WCA-2A; however, earlier data analyses reported by Kadlec and Newman (reference 23) supported the selected STA sizing approach. The key STA sizing parameter, the effective or net TP settling rate constant K_e, was conservatively estimated as 8 m/yr (references 23-25). Following subsequent data analysis of WCA-2A soil TP profiles, K_e was revised upward to 10.2 m/yr (references 1, 22).

These estimates of long-term phosphorus removal can be re-evaluated against the results of relevant research completed at the ENRP and other wetlands over the past five years. Considerable research conducted at the ENRP to refine the STA design basis and to provide guidance for operation of the STAs (references 26, 27) has generally demonstrated that the ENRP is functioning better for reduction of TP loads than originally expected. These data, as well as phosphorus performance data reported from selected treatment wetlands in Florida and world-wide, are evaluated in this section to:

- Update and refine the parameters used in the existing conceptual design model
- Identify the range of parameter values to be used for the TP performance model sensitivity analysis
- Review and suggest alternative approaches for estimating the likely performance of STA-3/4, and compare those approaches to the original design approach
- Recommend modifications to the basis of design concerning external and internal works
- Recommend additional studies that could be conducted within the time frame of the design project that will provide a basis for refinements to the STA-3/4 design

This evaluation of the STA-3/4 design basis addresses the ability of this new treatment marsh to meet or exceed the Phase 1 goal of the EFA (50 ug/L TP, 80% TP load reduction for the Everglades Protection Area, and 85% TP load reduction for the Loxahatchee National Wildlife Refuge), and describes proven and promising methods that might help improve treatment performance within the existing planned treatment area. It is not the intent to extrapolate this information to issues related to STA sizing; such issues will be addressed elsewhere with due consideration for the specific requirements of both the EFA and the Consent Decree.

3.2 EXISTING BASIS OF DESIGN

3.2.1 Existing STA Design model

The existing model for estimating STA outflow TP concentration was developed by Walker (reference 21) in concert with Kadlec and Newman (reference 23). This model can be expressed as:

$$C_2 = \{C_1-[(RC_R)/(K_e+R\text{-}ET)]\}[(1+R\text{-}ET)A/Q]^{-[(Ke+R\text{-}ET)/(R\text{-}ET)]}+[RC_R/(K_e+R\text{-}ET)] \quad [1]$$

where:

C_1 = average TP inflow concentration, mg/L

C_2 = average TP outflow concentration, mg/L

R = annual average rainfall, m/yr

ET = annual average evapotranspiration, m/yr

C_R = average TP concentration in rain (wet + dry deposition), mg/L

K_e = effective TP first-order area-based settling rate, m/yr

A = wetland surface area, m^2

Q = average inflow, m^3/yr

Equation 1 requires knowledge of average rainfall, evapotranspiration (ET), average inflow TP concentration, average rainfall TP, average inflow rate, wetland area, and the effective settling rate for TP, K_e. Parameter values used in the conceptual design report (reference 1) are summarized in Table 3.1. This equation was used to estimate that approximately 6,742 ha would be required for STA-3/4 to meet an annual average flow-weighted outflow TP goal of 0.05 mg/L.

Analysis of the individual input parameters in Equation 1 indicated that the model is most sensitive to the values of K_e and the average inflow TP concentration, C_1. As written in Equation 1, this model is also very sensitive to wetland area, average inflow, and hydraulic loading rate (q = Q/A). The sensitivity analysis conducted by Burns & McDonnell (reference 1) indicated that the required STA area is relatively insensitive to rainfall and ET, and to rainfall TP concentration. However, the lowest possible outflow TP concentration predicted by the model is highly dependent upon the rainfall TP concentration. Based on the input parameters in Table 3.1, the existing STA design model estimates a minimum achievable background TP concentration of 0.006 mg/L. This model is unsolvable for the special case when rainfall and ET are identical.

3.2.2 Revised Parameter Values for the STA Design Model

Efforts to predict STA performance over short time periods are underway by the District with development of the Wetland Water Quality Model (WWQM). To date, prediction of the seasonal and stochastic variation in effluent TP concentrations from the ENRP has defied exact replication by the WWQM.

Design of STA-3/4 does not need to rely on detailed predictions of daily or monthly patterns of effluent TP. Rather, annual average concentrations and loads to downstream ecosystems must be accurately estimated based on treatment wetland area and TP loading. These estimates will also allow conservative design and assessment of the appropriate level of additional treatment needed during Phase 2.

Ongoing work since 1994 has provided updated estimates of rainfall, ET, rainfall TP loads, and TP settling rates. Changes to anticipated inflows and TP loads are described elsewhere in this report. Based on Table 2.23 in the *Inflow Volumes and Loads* section, the revised average annual inflow to STA-3/4 will be about 790,600,000 m^3/yr. The revised annual average TP loading to STA-3/4 will be about 0.118 mg/L.The influence of potential changes in inflow volumes and loads, as discussed in Section 2 of this *Alternatives Analysis*, on the treatment performance of STA-3/4 will be evaluated further in Section 10 .

Rainfall quantities in south Florida are highly variable, both spatially and temporally. Abtew and Khanal (reference 28) estimate the mean rainfall over the Everglades Agricultural Area (EAA) as 1.21 m based on the period-of-record from 1973-1991. Mean rainfall for this same area was historically higher (1.33 m for 1929-1990) and the observed decline during the past two decades is statistically significant.

Summaries of estimated rainfall and reference evapotranspiration for calendar years 1965-1995 were furnished by SFWMD in February 1999. Those summaries were extracted from the South Florida Water Management Model (SFWMM) for the cells approximating the footprint of STA-3/4 to produce a spatial average for that region. Additional detail on the manner in which those estimates were derived may be found in the *DRAFT Documentation for the South Florida Water Management Model;* Hydrologic Systems Modeling Division, Planning Department, South Florida Water Management District; 1997.

Rainfall estimates provided by SFWMD have been used without adjustment; a monthly summary of the spatially averaged rainfall depths over the cells approximating the footprint of STA-3/4 is presented in Table 3.2. For the 31 year period including calendar years 1965-1995, the estimated average annual rainfall on STA-3/4 would have been 50.68” (1.29 m). For this evaluation, an average rainfall amount of 1.29 m/yr is applied for the Equation 1 analyses reported below. A range of average annual rainfall amounts between 1.19 and 1.51 m/yr is recommended for subsequent model sensitivity analyses.ET rates have received extensive study in the ENRP. These rates appear to be affected very little by plant community composition in flooded wetlands and are approximately equal to lake evaporation (reference 29). Average ET rates in ENRP cattail (*Typha* spp.) plant communities were 3.6 mm/d (1.31 m/yr) over a two-year period (reference 30). This ET rate is roughly equal to 80% of pan evaporation.

As for rainfall, the District has estimated spatially-weighted ET values in a 2x2 mile grid approximating the footprint of STA-3/4. These ET estimates were developed using the Penman-Monteith equation referenced to a dense grass cover of 12 inches in height. It was necessary to adjust the reference ET estimates provided by SFWMD to reflect the anticipated land use (e.g., “crop type”) and water depths in the STA. Those adjustments were made using the methodology and factors described in the draft SFWMM documentation. For this analysis, the depth of water above the land surface was established at the intended mean depth of 2.0 feet. A monthly summary of the resultant spatially averaged ET depths over the cells approximating the footprint of STA-3/4 is presented in Table 3.3. For the 31 year period including calendar years 1965-1995, the estimated average annual ET from STA-3/4 is estimated as 58.68” (1.49 m). This average value for ET is used in the preliminary performance analysis described below. A range of average annual ET estimates between 1.47 and 1.53 m/yr is recommended for the performance model sensitivity analyses.

Detailed hydrologic modeling of STA-3/4 to be conducted during the Plan Formulation phase should compute daily ET using the algorithms reflected in the SFWMM (e.g., ET can be expected to vary not only temporally, but also with respect to depth of water). Wet and dry deposition of TP has been the subject of continuing research in the EAA (references 31, 32). The average TP concentration in rainfall was 0.011 mg/L at 15 sites summarized by Ahn (reference 31). Given this value and Ahn’s estimated rainfall of 1.35 m/yr, total annual wet phosphorus deposition is estimated to be 14.3 mg TP/m^2/yr. Dry deposition accounts for another 32.1 mg TP/m^2/yr, for a total wet and dry deposition average of about 46.4 mg TP/m^2/yr. Based on an estimated annual average rainfall total of 1.29 m/yr, this deposition would be equal to an average wet and dry TP concentration of 0.036 mg/L. A total average atmospheric TP input concentration of 0.04 mg/L is applied for the design and performance estimation presented below.

The determination of the most appropriate TP settling rates for estimating STA-3/4 performance has been an area of active research and data analysis. As discussed above, early work during conceptual design indicated that the TP settling rate appears to be variable between different treatment wetland projects. Wetland start-up phenomena may allow the TP settling rate to be overestimated in some instances (reference 21). TP settling rates can be reduced by dry-down effects (references 14, 22), hydraulic short-circuiting (i.e., the inability to accurately estimate q – the actual hydraulic loading rate), and inadequate data collection that does not allow assessment of the complete TP mass balance and the potential for groundwater TP fluxes. Successional and seasonal factors can contribute to large seasonal and annual variation in TP settling rates within a single project (reference 29).

Average measured TP settling rates are summarized in Table 3.4 to provide a comparison and selection of the most relevant rate to use for the STA-3/4 design. Of particular interest are the TP settling rates being estimated from the ENRP over the four-year operational period. The ENRP settling rates are relevant to the STA-3/4 design because of the similar project scale, climate, biology, and inlet water quality. However, it is acknowledged that the ENRP has been operated in a manner that may be hydraulically dissimilar to anticipated STA operations. While mean water depths are intended to be similar, the temporal distribution of inflows is expected to be very different. Peak hydraulic loading rates will be much higher in STA-3/4 while mean hydraulic loading rates will be lower. Therefore, it is reasonable to expect that the temporal distribution of flows through STA-3/4 will fall somewhere between the relatively uniform loading of the ENRP and the highly variable inflows demonstrated historically out of the EAA for flood protection purposes. On this basis, the TP settling rates demonstrated thus far for the ENRP are likely on the high side.

The overall TP settling rate for the ENRP has been estimated between 15.5 and 18.5 m/yr (reference 33). Highest settling rates have been estimated for the Buffer Cell (62 m/yr) and for Cell 4 (38.5 m/yr). Overall ENRP settling rates were highest during the first two years of operation. However, to date, no significant decline in average TP settling rate has been demonstrated since the end of 1996 (reference 33). No decline in TP settling rate has been observed in the Buffer Cell or in Cell 4 throughout the life of the ENRP.

3.3 OTHER MODELING APPROACHES

3.3.1 Settling Rate With an Irreducible Concentration

Settling rates calculated based on inflow/outflow data have the potential to underestimate the actual effective settling rate within a wetland. This mathematical artifact results from the exponential character of TP disappearance between the inlet and outlet and the use of a single straight-line model for estimating removal rate (reference 29).

The simplest expression of the first-order, area-based plug flow wetland performance model, assuming no net rainfall or seepage, is:

$$\ln (C_1/C_2) = k_1/q \qquad [2]$$

where:

C_1 = average inlet concentration, mg/L

C_2 = average outlet concentration, mg/L

k_1 = first-order, area-based rate constant

q = average hydraulic loading rate, m/yr

This is the general form of the model that has been used to develop many of the TP settling rates summarized in Table 3.2 and will be referred to as the one-parameter or k_1 model.

Data from many treatment wetlands indicate that internal and external loading of TP may result in a non-zero, irreducible wetland water column phosphorus concentration. For some purposes this concentration may be so low as to be indistinguishable from zero, but in the case of the STA designs, performance expectations are approaching the lowest TP concentrations measured in nature. In this situation, the plug flow model can be corrected by introducing a second parameter that represents the lowest achievable or irreducible concentration that will occur in a treatment wetland, C*. The two-parameter first-order, area-based plug flow model, or k-C* model, is:

$$\ln[(C_1\text{-}C^*)/(C_2\text{-}C^*)] = k/q \qquad [3]$$

Profile data provide a more accurate method of data analysis when there is a non-zero irreducible background concentration and the wetland outflow concentration is near this background. An example of this effect is illustrated in Figure 3.1 for an analysis of operational data from Boney Marsh. TP profile data were reported from Boney Marsh for the period from April 1978 through April 1979 (reference 14). The right side of Figure 3.1 illustrates the data fit obtained by applying the plug-flow, first-order k_1 model to the inflow/outflow data for Boney Marsh with the assumption that the irreducible background TP is equal to zero. This data fit estimates the TP settling rate as 11.5 m/yr with an $r^2 = 0.64$. The left portion of Figure 3.1 illustrates the effect of fitting the two-parameter, k-C* model to these profile data. The TP settling rate is estimated as 39.0 m/yr with a C* of 0.013 mg/L and an r^2 of 0.99.

Profile data for other Florida treatment wetlands are fitted to the k-C* model in Figures 3.2 through 3.5. The estimated TP model parameters estimated for the k-C* model are summarized in Table 3.5. The relatively low value for k for the Titusville data cannot be explained based on available information concerning this relatively new site; however, antecedent soil conditions on this former pasture land may be temporarily masking a higher sustainable TP removal rate in this wetland. The high C* estimates for Titusville and Iron Bridge may reflect higher rainfall TP conditions or biological differences between central and south Florida wetlands.

3.3.2 Wetland Degree of Mixing

Treatment wetlands do not perform as perfect plug-flow systems (reference 34). Tracer data from a variety of treatment wetlands indicate that their hydraulic mixing behavior is intermediate between two ideal hydraulic models, plug flow and complete mix or continuously stirred tank reactor (CSTR):

$$(C_2\text{-}C^*)/(C_1\text{-}C^*) = 1/(1+k/q) \qquad [4]$$

Length-to-width ratio does not appear to affect this inherent degree of mixing, indicating that it occurs on a relatively small scale. This behavior of treatment wetlands can typically be modeled as 2 or 3 CSTRs in series using the Tanks-in-Series (TIS) model:

$$(C_2\text{-}C^*)/(C_1\text{-}C^*) = (1+k/Nq)^{-N} \qquad [5]$$

where:

N = number of tanks in series

Figure 3.6 illustrates the effects of these differing flow regimes on the treatment wetland area necessary to achieve a given pollutant average outflow concentration. The plug flow system is the most efficient and the CSTR is the least efficient. The TIS system is intermediate in performance. The actual STA-3/4 design example is illustrated in Figure 3.6. For a given value of k_{TP}, approach to plug flow through careful design and construction could result in a further reduction of TP concentration by more than 10 ug/L.

Although the TIS k-C* model is more realistic of actual treatment wetland behavior than the plug flow version of the model, there are no south Florida treatment wetlands that have been tracer tested to determine their degree of mixing. Therefore, values for k that have been developed for the plug flow model assumption must be applied using the same plug flow model when estimating STA-3/4 performance.

3.3.3 Infiltrating/Exfiltrating Wetlands With Storage

The models described above do not include the possible effects of more complex water budget considerations. For example, the annual quantity of water gained and lost by a wetland due to rainfall and ET is rarely equal. Thus surface water in a wetland is either diluted or concentrated, depending upon the net effect of rain and ET. Similarly, the stored volume of water in a wetland is not constant, and this change in storage alters the steady-state, plug-flow assumption. Finally, wetlands in south Florida are often subject to significant groundwater exchanges resulting in potential inflows of groundwater and seepage of surface waters out of the wetland to adjacent lands. All of these water balance factors can be incorporated in the performance estimation model assuming plug flow hydraulics:

$$(C_2-C^*)/(C_1-C^*) = (1+\alpha/q)^{-r} \quad [6]$$

$$\alpha = (R-ET+I_i-I_o-\Delta S) \quad [7]$$

$$r = \gamma/\alpha \quad [8]$$

$$\gamma = R-ET+I_i+k \quad [9]$$

where:

I_i = infiltration into the wetland from the groundwater, m/yr

I_o = infiltration out from the wetland to the groundwater, m/yr

ΔS = change in storage, m/yr

C* in this model combines the effects of internal loading, rainfall, and infiltration on the irreducible wetland outlet concentration. For example, groundwater upwelling in the wetland may carry higher TP concentrations and result in a higher background just as higher rainfall TP can result in a higher background. In this case, C* can be estimated from the following expression:

$$C^* = (kC_\lambda + RC_R + I_iC_i)/(\alpha + k + \Delta S + I_o) \qquad [10]$$

where:

C_λ = the TP concentration resulting from internal loading by soils and ecological processes, mg/L

C_i = the TP concentration in the upwelling groundwater, mg/L

This formulation of the k-C* plug flow model should be used for estimating performance of STA-3/4 if seepage and associated TP concentrations are significant.

3.4 REVISED BASIS FOR STA PERFORMANCE ESTIMATION

The existing STA design model (Equation 1) provides a powerful tool for estimating performance of STA-3/4. However, recent data collection and analysis indicate that some of the input parameters for this model should be updated. Specifically, estimated average rainfall and maximum ET can be revised based on recent data analyses summarized above. The value for K_e should be revised to reflect higher rates of performance in the ENRP. The recommended revised value for estimated maximum K_e is 18.5 m/yr based on Chimney and Moustafa's analysis of ENRP performance data (reference 35). This value assumes that STA-3/4 will not be dry for any extended periods, and a lower value comparable to Boney Marsh (about 13 m/yr) should be used if the STA will go dry on an annual basis. Table 3.6 illustrates these revised parameter values and their effect on estimated STA-3/4 performance. The long-term annual average outlet TP concentration is estimated as 0.027 mg/L.

The existing STA design model cannot be explicitly calibrated to locally variable values of C*. As described above, C* varies due to factors other than rainfall TP concentrations, including internal TP cycling differences between differing wetland plant communities and differences in external loadings from upwelling groundwaters. The relatively simplistic k-C* model (Equation 3) incorporates these effects and can be calibrated using profile data from a number of macrophyte-dominated wetlands in south Florida. Preliminary estimates of these two parameters are provided above and summarized in Table 3.6. Values of k_{TP} = 30 m/yr and C* = 15 ug TP/L are offered as a preliminary basis for performance estimation for a cattail-dominated wetland with this model. Figure 3.7 provides an estimated profile of TP concentrations with distance through the proposed STA-3/4 based on the k-C* model without infiltration or upwelling. This revised approach for assessing TP performance estimates an annual average outflow TP concentration of about 22 ug TP/L for STA-3/4. As described below, however, it should be noted that other factors may substantively modify the net performance achievable with these STAs.

The actual STA-3/4 treatment wetland will have an imbalance between rainfall and ET and will have non-zero exchanges with groundwater. The magnitude of the groundwater exchanges will be estimated during preliminary design. It is currently anticipated that groundwater inputs to STA-3/4 will be negligible but that groundwater outputs may be significant. A preliminary estimate of infiltration rate in the footprint of STA-3/4 is provided by the SFWMM, which is a regional scale hydrologic simulation model. The estimated infiltration rate in that model is 0.1 m/yr. Estimated infiltration rates in other recently constructed stormwater treatment areas have reflected significantly higher overall rates of infiltration. The more pertinent previous estimates are considered to include those prepared for Stormwater Treatment Area No. 5 (estimated by Burns & McDonnell as an average of 0.93 m/yr) and for Stormwater Treatment Area No. 2 (estimated by Brown & Caldwell as an average of 3.5 m/yr). Those estimates include all infiltration, including perimeter seepage, assuming no return of seepage to the treatment area interiors.

The k-C* model formulation with atmospheric and groundwater interactions (Equations 6-10) is recommended for ultimate performance estimation once these additional data are available. Table 3.7 provides a summary of expected performance levels for STA-3/4 based on a variety of assumptions concerning groundwater interactions and internal P loading. The value of C_λ in Table 3.7 is estimated based on a resulting value of C* = 15 ug/L. High exfiltration rates with high TP groundwater concentrations result in decreased STA performance. Internal TP loading with a higher TP removal rate constant results in predicted higher performance. High infiltration rates result in improved performance based on surface water TP concentrations and loads. Storage also results in improved performance.

3.5 RECOMMENDATIONS FOR WETLAND INTERNAL AND EXTERNAL DESIGN MODIFICATIONS

3.5.1 Wetland Short-Circuiting

Tracer tests in treatment wetlands, including the ENRP, have demonstrated that water flows are often short-circuited due to poor inlet distribution, preferential flow channels, topographic irregularities, and uneven water control structures. Figure 3.8 presents an indication of this inefficiency observed during a tracer test of the ENRP buffer cell and the front end of Cell 1. The volume of the Buffer Cell is not known but was estimated based on a measured area of 53.8 ha and an estimated average depth of 0.75 m. Based on this assumption, the average nominal residence time during this tracer test was 20 hours. Actual measured hydraulic residence times varied from about 10.4 to 30.7 hours at the 10 culverts that transfer water into Cell 1. Flows short-circuit to the end culverts, G252A and G252J, and reach culvert G252E after a considerable delay.

Short-circuiting in treatment wetlands can result in hydraulic inefficiencies due to the bypass of significant potential treatment areas/volumes. Preliminary tracer testing from the 504 ha Lakeland, Florida constructed treatment wetland indicates that as little as 17 to 46 percent of the estimated volume of three large cells at this wetland is actually in the water flow path (Figure 3.9). Even carefully graded treatment wetlands such as the Tres Rios Demonstration Wetlands in Phoenix, Arizona have up to 30 percent of their estimated volume excluded from treatment (Figure 3.10). Effective flow distribution, both into and out of a treatment wetland, is essential to minimize hydraulic inefficiency. It is likely that the very large cells of the ENRP and STA-6 have severe hydraulic short-circuiting approaching the levels found at Lakeland. Channels parallel to the flow direction, even if plugged at regular intervals, have the potential to create preferential flow paths and very short hydraulic residence times.

Internal flow re-distribution appears to be an effective method to reduce short-circuiting in treatment wetlands (reference 29). Transverse deep channels such as those illustrated in Figure 3.10 for the Tres Rios wetland act to re-establish sheet flow through the downstream marsh segment. Internal levees and weirs can provide the same function but may be more costly to construct. Any existing transverse ditches within the footprint of STA-3/4 should be considered for preservation. Longitudinal ditches and channels need to be entirely filled and leveled to avoid the opposite effect of promoting short-circuiting.

3.5.2 Enhancing the Degree of Mixing

As demonstrated in Figure 3.6, the actual degree of mixing of a treatment wetland affects its TP removal performance. Unfortunately, quantitative data on the effects of internal design criteria on wetland hydraulics are limited. Only a few treatment wetlands have been tracer tested with different internal design configurations. The two systems that have purposely looked at this design variable were the abovementioned Tres Rios wetland, with varying numbers of transverse deep zones, and the Champion pilot constructed wetlands in Pensacola, Florida. At both of these sites it was found that the degree of mixing is improved by incorporating deep zones. Also, at Tres Rios it was found that multiple deep zones evenly spaced along the length of the wetland increase the plug flow performance characteristics. For this reason it is recommended that transverse deep zones be considered throughout all cells in STA-3/4 at regular intervals. Two-dimensional hydraulic modeling of flows through the STA-3/4 system should include evaluation of the flow benefits of including transverse deep zones in the designs; this might merely translate to development of guidelines regarding the disposition of existing agricultural canals. On the basis of information currently in hand, it would seem potentially beneficial to leave existing canals that are oriented transversely to the anticipated flow path in place as a mechanism for fostering sheet flow through the cells.

A final recommendation pertains to performance of additional testing of flows through the ENRP test cells and/or operational cells in STA 6 to more directly assess hydraulic performance of STA cells. A tracer test to track the passage of a truly inert substance such as lithium or bromide through such cells would shed significant light on the hydraulic efficiency and degree of mixing achieved with the existing STA designs, and therefore the relative need to incorporate some of the recommendations provided above. Without such testing results, it would be prudent to adopt these recommended modifications under the presumption that they will likely improve estimation of probable STA performance, as well as anticipated hydraulic efficiency and therefore actual TP removal capacity.